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Comparative Anatomy
Of Highway Bridges

Civil Engineering

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COMPARATIVE ANATOMY
OF
HIGHWAY BRIDGES

BY

JOHN KRIPPNER

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

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OF Bachelor of Science in Civil Engineering

Irvin O. Baker

HEAD OF DEPARTMENT OF Civil Engineering

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HEAD OF DEPARTMENT OF
CIVIL ENGINEERING

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INTRODUCTION.

Much has been written about the calculation of stresses in bridge members and the way of determining the area of the sections, but no comparison of the methods used by different bridge companies in joining the several members has ever been made. The importance of well designed connections can not be overestimated. It has been said that the designing of the principal details is even more important than the determination of the stresses and the sections, since the life of a structure depends largely upon the method of connecting the main members. "Cheap" and faulty details may double the stresses in the main members, and yet such details will be passed without criticism by any one but a trained engineer.

In order to make a comparison of standard details, the author investigated the shop drawings of over fifty highway bridges built by fifteen different companies in the West, the drawings being in the possession of Civil Engineering Department. These bridges were all Pratt-truss, pin-connected spans, varying from 70 to 160 ft. in length, except one riveted span, and all were through trusses except four. Plate 1 gives the names of builders, length of bridge, width of roadway, and other information of general character pertaining to the bridges here investigated.

Plates 3, 4, 5 and 6 show the details to be considered in this discussion. No special effort was

made to draw these sketches to scale, as the chief object in presenting them was to show as many methods as practicable.

ART. I. FLOOR SYSTEM.

The floor system of highway bridges consists of the following:

- a. Floor beams.
- b. Joists.
- c. Wall plates.
- d. Wooden floor.

a. Floor Beams. The floor beams are almost invariably composed of rolled I beams, although formerly, owing to an arbitrary and excessive price of I beams, it was cheaper to use a built-up section for a floor beam. Some of the methods of connecting the floor beams to the posts will now be discussed.

On general, the connection may be above or below the pin. The former is the better, since it gives greater stiffness to the post, and also transfers the force of the laterals more directly to the post. On the other hand, placing the floor beam above the pin requires a greater depth of truss for the same head-room than if the floor beam were below the pin.

Fig. 1, Pl. 3, shows the earliest and poorest connection of the floor beam to the post. This connection

was largely used in the past, but has been almost abandoned. The chief objection to it is that the floor beam is not rigidly connected to the post, and that no adequate means is provided of transferring the stress of the bottom lateral to the main truss. The only rigidity in this connection is due to the friction between the top of the floor beam and the bottom of the post caused by screwing up the nuts at the bottom of the stirrup; but unfortunately, when the load comes upon the floor beam, the stretch of the stirrup destroys the contact, and therefore, the bridge is least rigid when rigidity is most needed.

Fig. 2, Pl. 3, shows the method of connecting the floor beam to the vertical post below the pin by attaching vertical hanger plates to the channels and inserting a diaphragm between the hanger plates to transfer the stress from the inside to the outside hanger plate. To make this connection in the field, the floor beam is first placed in position, and the vertical post is set up and bolted to the floor beam.

Fig. 3, Pl. 3, shows a method of connecting the floor beam below the pin by attaching hanger plates to the channels and cutting a vertical slot through the inner hanger plate and notches in the upper flange of the floor beam. Notice that Fig. 3 requires a longer floor beam than does Fig. 2; while by the method of Fig. 3 the stress is doubtless more equally divided between the two hanger plates.

Fig. 4, Pl. 3 shows the method of supporting the floor beam below the chord at the lower end of the

hip vertical. The suspending plate is always riveted to the floor beam in the ship. See Fig. 15 for a slightly different form of this connection.

Fig. 5 differs from Fig. 2 in that a built floor beam is shown instead of a riveted one, and also in that the diaphragm consists of two channels instead of a plate and four angles. The latter construction is cheaper than the former in that it has two rows of rivets less.

Fig. 7 shows a method of connecting a rolled floor beam to the post above the pin. Notice that this connection is similar to Fig. 2, except that in Fig. 7 the connection is directly to the channels, while in Fig. 2 it is to a vertical hanger plate below the pin.

Fig. 8 shows the connection of a built floor beam to a channel post. Notice that the end of the floor beam is inserted between the channels and is connected to a long batten plate on the outside of the post, and rests upon a short batten plate on the inside of the post.

Fig. 15 shows a method of hanging a floor beam below the pin, ~~and~~ specially designed for the lower end of the hip vertical. For a somewhat similar connection see Fig. 4.

Statistics seem to show that the method of connecting the floor beams below the pin is more popular, as the number of cases in favor of this method is 34, while only 16 cases of floor beam connection above the pin were noted in the bridges here investigated.

b. Joists. Joists are the beams laid parallel to the trusses on the floor beams, which support the wooden floor. On the older structures they were of wood, as this was cheap and plentiful; but in modern practice wooden joists are no longer used on account of the increasing difficulty of securing good, particularly long, timber. In all bridges here investigated the joists are of steel, — I beams or C^s (channels). The channel joists are always placed at the edge of the roadway, one at each side. ~~for~~ The channels have a little more than half of the strength of the I beams, and when placed as above carry about half as much load as comes upon the I beams, and consequently are equally efficient. The joists, whether I^s or C^s , are set directly on top of the floor beams, and are secured to them by one or two bolts at each end.

c. Wall Plates. Wall plates are some form of support placed upon the masonry abutment to raise the joists above the bottom lateral rods; and when used for this purpose alone, may consist of a small cast iron block or foot under each joist. But this construction is not very common and ^{is} very undesirable — as will appear incidentally presently.

It is better to combine the joist raiser, joist spacer, and shoe strut into a single member. A simple method of doing this is to lay a channel on the masonry with its legs up and into it place a smaller channel with its legs down, the joist being bolted to the web of the small channel and the web of the

lower channel being fastened to the shoe. For an example of this construction, see Fig. 14, Pl. 3.

Fig. 9, Pl. 3, shows the method of connecting an I beam wall plate and shoe strut to the shoe. The anchor bolt in the wall plate is unusual, unnecessary and undesirable.

Fig. 10 shows a form of joist raiser, joist spacer and shoe strut, and also the method of connecting the shoe strut to the shoe plate. Notice the slots in the web of the channels to permit the expansion of the joist. The slot in the connection to the shoe plate is unusual and unnecessary. This form of wall plate is unsatisfactory as the bearing is concentrated on the somewhat sharp edges of the flanges of the I beam. Fig. 14 is free from this objection.

Fig. 14 shows an excellent form of shoe strut and joist raiser, except that the connecting plate at the end is too light to enable the member to act as a strut in any but a very short span.

Some of the above forms of wall plates was used in all bridges under discussion, except one in which no wall plate was used, ~~at all~~, the joists being set directly on the masonry.

d. Wooden Floor. The wooden floor should be composed of planks having a thickness in inches not less than the distance between the joists in feet, with a minimum thickness of $2\frac{1}{2}$ inches. The minimum thickness usually governs, as the joists seldom exceed $2\frac{1}{2}$ ft center to center. In general, the planks should be laid with openings $\frac{1}{4}$ to $\frac{1}{2}$ inch wide for drainage.

To insure good fit, the planks should be straight, and if slightly curved, the concave side should be put next to the joist. In all cases the plank should bear firmly upon the beams and should be fastened securely to them. There are several methods of attaching the planks to the joists, the more common of which, will be described.

1. By clinching the nails. This method is illustrated by Fig. 18(a), Pl. 4, and consists of driving the nails close to the joists and then bending them under the flanges of the latter. This method is widely used, as it has the advantage of simplicity and may be executed in short time. It is not good practice, however, for the nails will soon work loose.

2. By driving nails through nailing pieces laid on top of the joists and fastened to them by bolts. This method is shown in Fig. 18(b), Pl. 4, and requires one nailing strip for each joist. The strips are usually about two inches thick, so that the nails can not be more than about four inches long. To make good connection, however, longer nails are necessary, which in turn require deeper strips. Hence, if this method is made efficient, it is not economical; and vice versa.

3. The third method consists in attaching nailing pieces to the web of the joists, the top being flush with the top of the joists, as shown in Fig. 18(c), Pl. 4. This method is economical, as only two or three nailing pieces are required; and it is also efficient, as the nails may be long enough to get firm bearing.

Specifications usually call for a felloe guard to be placed at the side of the roadway to protect the steel mem-

bars of the truss. The position of the felloe guard with reference to the C joist is shown in Fig. 19 (a) (b) (c), Pl. 4. Notice that in Fig. 19 (b) one bolt passes through the felloe guard, the plank, and the flange of the joist; while in Fig. 19 (a) and (c) two bolts are required. Sometimes three felloe guards are specified, one of which to be placed at the center of the bridge, so as to divert the traffic in two roadways and thus distribute the wear more uniformly. In order to assist the drainage, the wheel guards are often supported on blocks spaced 4 or 5 ft apart, as shown in Fig. 19 (c). The same figure also shows another feature commonly seen on the felloe guards, and that is the small angle iron at the upper edge to protect the felloe guard against injury from traffic. The utility of felloe guards is more or less doubtful, and in modern bridges they are often omitted.

Occasionally, there is an additional wearing floor, $1\frac{1}{2}$ " thick, specified. When such is the case, the bottom planks are laid diagonally across the bridge (at 45°). This construction necessitates the tearing up of a large part of the top flooring, in case of the failure of a plank at the bottom. See Fig. 19 (e) Pl. 4, for an arrangement of double flooring.

Art. II. HIP VERTICALS.

The hip vertical is occasionally composed of a single loop bar, as shown in Fig. 15, Pl. 3; but usually consists of two loop bars, as shown in Fig. 17, Pl. 3. In the latter case the loop bars sometimes reach from the hip to the lower chord pin, but sometimes only from the top chord to the top of a short post - called a sub-post. This latter construction is shown in Fig. 13, Pl. 3. The sub-post affords a good connection for the floor-beam and for the hub-guard, but on the other hand costs considerably more than the two simple loop bars.

Notice in Fig. 15 the manner of supporting the fence. As far as the method of supporting the fence is concerned this construction is practically as good as the sub-post shown in Fig. 13. For a further discussion of method of supporting the fence see Art. X.

With riveted trusses the hip vertical is of necessity a stiff member and is usually composed of two angles; but this section is not economical, as the stresses in the hip vertical are not great, and often, upon investigation, the efficiency of this section is found to be as high as 200-300 per cent, which is too extravagant.

Art. III. INTERMEDIATE POSTS.

In the earlier days of steel bridge building the favorite section of some manufacturers was an I beam placed with the web at right angles to the roadway. These I beams were connected by horizontal rods, $\frac{5}{8}$ to $\frac{3}{4}$ inch in dia., called "diastictus rods," passing from the center of one post to the center of the next in the same truss. The result was that in course of time the posts bent to one side or the other, and sometimes to both. The principal objection to using I beams for posts is their lack of rigidity in resisting the wind pressure in the plane at right angles to the web.

The most approved section for the intermediate post is two channels connected by lacing. The channels may be placed with their webs either perpendicular or parallel to the roadway. Fig's 5, 6, 7, 12, Pl. 3, and Fig. 21, Pl. 4, are examples of the latter, and Fig. 8, Pl. 3, and Fig's 22, 23, Pl. 4, are examples of the former. Therefore both forms are common and the writer has not discovered the reasons for choosing one in preference to the other.

Posts whose webs are parallel to the roadway may have the chord pins pass through the webs of the channels and so do away with the heavy pin plates necessary when the webs of the channels are at right angles to the roadway, but unless there are heavy batten plates at the foot of the post to transmit the load on to the floor beam, the stresses will not be evenly distributed between the channels. Putting the channels per-

pendicular to the roadway distributes the stress more evenly between the channels. Of bridges here investigated, 37 had posts with channels parallel to the roadway and 21 perpendicular to the same.

The flanges of the channels composing the posts may be turned in or out. Theoretically, it is more economical, so far as the area of the section is concerned, to turn the flanges in, for the moment of inertia is then greater; but on the other hand, the difficulty encountered in riveting in a confined space, more than offsets this advantage. While it is not an impossibility in our days of pneumatic hand riveters to do good riveting in a closed section, the cost is greater than with the ordinary riveting machine, and greater than the price of the little extra metal saved. Of the bridges here investigated only one has the flanges of the channels turned in; and that is a riveted truss, No 19, Tab. I, Pl. I, which seems to be peculiar in several other particulars although it also seems to be a good bridge.

If the channels are placed with the web parallel to the roadway, there is a slight advantage in turning the flange in, since in that case it is not necessary to cut the flanges off to enter the post between the channels of the top chord; but this objection is trivial, since the intermediate posts of highway bridges usually have a great excess of metal, and further since the weakening due to removing the flanges is quite small. It has been shown by experiments made by Chicago & Alton R. R., as given in a paper read before the Western Society of Civil Engineers by Mr. E. J. Ward, that this

cutting away reduces the strength of the post about ten per cent. The advantage of turning the flanges in is, however, partially counterbalanced by the increased size of pin necessary on account of greater leverage of the stresses in the diagonals - these being farther apart.

Fig. 6, Pl. 3, shows a method of connecting the top of the intermediate or vertical post to the top chord when there is no splice in the top chord near the connection. When there is a top chord splice, the vertical connecting plate is extended on the side toward the splice so as to give a vertical row of rivets beyond the splice. For a somewhat similar method see Fig. 12, Pl. 3.

ART. IV. MAIN AND COUNTER TIES.

As the main and counter ties of highway bridges are usually small, they are more frequently made of loop bars than of eye bars. For a further discussion of loop and eye bars see Art. VI.

In his treatise on Highway Bridges, Waddell shows that the economical depth of the eye bars varies from four to six times the width. The counter ties should be square or round to avoid unsightly appearance due to the change of cross section by upsetting of the end to receive the turn-buckle. Usually they are made of the least allowable cross section; about $\frac{7}{8}$ in. round or square. As a rule, only one rod is used, which is made adjustable

by a sleeve nut or a turn-buckle. The proper place to put the turn-buckle is as high as possible, in order to prevent its being tampered with by ignorant or malicious persons, after the adjustment is once made. This advantage, however, is not generally recognized, the turn-buckle usually being placed in the lower part of the truss, within the reach of everybody.

Fig. 21, Pl. 4, shows the relative position of the main and counter ties with reference to the members of the lower chord. Notice that only one rod $\frac{3}{4}" \phi$ is used for the counter, and this is placed to one side of the center of the pin; such arrangement results in unsymmetrical loading on the pin, and is, therefore, poor design.

Fig. 22 shows the packing of main and counter ties in the lower chord at L2, when the channels are placed perpendicular to the roadway. In this construction the counter tie is placed at the center of the pin, and hence it is free from the objection referred to in Fig. 21. On the other hand, another objection to this practice is that it increases the bending moment on the pin, which would be less if there were two counters placed symmetrically about the center of the pin.

Figs 23 and 24 obviate the objection to the method in Fig. 22, so far as symmetrical loading on the pin is concerned; but such construction is more expensive and usually is not strong enough at the juncture of the two loops, especially if these are as wide apart as in Fig. 23. Nevertheless, a forked counter like the one shown in Fig. 24 is very common.

Art. V. END POSTS^{or} UPPER CHORDS.

End posts and upper chords are usually made of the same cross section throughout. This practice results in somewhat varying efficiencies of the top chord members. On the end post, owing to the stresses caused by the wind, the efficiency is the minimum; while in the end panels of the upper chords, where the stresses are the least, the efficiency is a maximum. The reason for adopting a uniform cross section is mainly a practical one - for it simplifies certain details, such as spacing of rivets and lacing bars, so that one templet may be used several times over.

The common practice is to use two channels with a cover plate on top and lacing or latticing below. When single lacing is used, Cooper specifies that the angle between the lacing bar and the longitudinal axis of the member should not be less than 60° ; in double lacing 45° . In all cases here noted, where a top cover plate is used, single lacing on the bottom is employed, the bars being inclined at an angle of 45° . Such practice may still be satisfactory notwithstanding Cooper's specifications, since the cover plate has a greater effect on stiffening the member than double lacing. When double latticing is used, it is customary to rivet the lacing bars at their intersection; Such practice is commendable, for it stiffens the bars and also the laced member.

As it is often impossible to determine the shear in a member and to design rationally the size of lacing bars, these are usually assumed according to some specification.

According to Cooper's specifications the lacing bars should have a thickness not less than $\frac{1}{40}$ in single lacing, and in double lacing not less than $\frac{1}{60}$, of the distance between the rivets, connecting them to the main members.

The channels used for the top chord sections are designed by their moments of inertia and spaced apart so that the moments of inertia of the whole section in the horizontal and the vertical planes are equal. In order to counterbalance the stress due to the weight of the member, the pins should be placed slightly below the neutral axis. On the bridges investigated the writer observed that this idea of equalizing the stresses is rarely carried out; in fact, the pins are often located on the center line of the channels, which practice is not only disadvantageous, but is a positive detriment, as it renders the top plate almost useless in transmitting the direct stress.

The ends of all laced members should be stiffened by batten plates. These should be placed as near the end as practicable, and their length should never be less than the greatest width of the member, nor less than $1\frac{1}{2}$ times the least width.

The webs of the compression members must be reinforced by pin plates at each pin connection, so that the allowable bearing on the pin shall not be exceeded. The pin plates should be designed to take their portion of the total stress and should be long enough to allow the number of rivets required. ~~to be put in~~. The longest pin plate should overlap the batten plate by not less than two rows of rivets, or about six inches. For the relative position of pin plates and batten plates see Figs 20, 25, 26, 28, 29, Pl. 4.

Special care should be exercised in making the abutting joints of the chord members bear evenly at the splice. Cooper says that no reliance should be placed on the abutting ends meeting at the pin, and that the splice should be designed to transmit all the stress. To do this he specifies that the joints be spliced on all sides by at least two rows of closely pitched rivets. For a common form of splice see Fig. 12, Pl. 3.

ART. VI. LOWER CHORDS.

On the ordinary pin-connected highway bridges the lower chords are always composed of loop bars or eye bars. The difference between the loop and the eye bar is that the loop of the former is welded, while the eye of the latter is formed by upsetting; although some manufacturers make eye-bar heads in quantity and weld them to bars as needed. With either loops or eyes, the pin hole should be bored to procure a good bearing on the pin. The loop is made by turning the end of the bar over 180° , leaving sufficient clearance for the pin. The length allowed for the loop depends on the size of the pin, and must be sufficient for the proper welding. American Bridge Co. allows for the length beyond the center of the pin to form a loop, a distance in inches equal to $3.7(P+R)$, where P stands for the diameter of pin and R for the depth of the bar. The eye bar is made, as mentioned above, by upsetting the ends and drilling a hole equal to the diameter of

the pin plus $\frac{1}{32}$ " or $\frac{1}{64}$ " as the case may be. Specifications in regard to drilling the holes say that these should be in the axis of the member, concentric with the circumference of the head, and at proper distances apart, so that when two eye bars are laid one over the other the holes shall not differ by more than $\frac{1}{50}$ of an inch. In either case, whether loop or eye bar, the eye should be strong enough than when tested to destruction rupture will occur in the body of the bar rather than at the pin hole.

The packing of the lower chord must be such that the bending moment on the pin is a minimum. This condition is generally satisfied by placing the bars so that no two consecutive eye bars pull in the same direction. The most common arrangement is to place the eye bars composing the lower chord symmetrically about the center of the pin, on the outside of the intermediate posts; the diagonals and counters are then put inside the channel post, the former close to the channels, the latter near the center. The eye bars of the lower chord are always close together, but the diagonals must be secured in the proper position by means of filler rings. It is best to have the bars parallel, but a variation of one or two inches in twenty feet will make no appreciable difference in the bearing on the pin. It is also customary to allow $\frac{1}{16}$ " for each eye bar in figuring the grip on the pin, on account of the possible variation of the thickness.

Figs 21, 22, 23, Pl. 4, show forms of packing of the lower chords; these figures have been discussed more in detail on p. 14.

Fig. 16, Pl. 3, shows the relative position of the various

members on the pin. In this particular case the floor beam is below the pin and is supported by the hanger plates.

For the forms of packing of the lower chord at the hip vertical see Fig's 15 and 17, Pl. 3.

Art. VII. UPPER LATERAL SYSTEM.

The upper laterals in highway bridges are usually designed only for tension. Occasionally it is specified that they must be composed of shapes capable of resisting compression as well as tension, in which case angles are employed. The more common method, however, and the one adopted in all the bridges under discussion, is the use of single rods which are made adjustable by nut and thread. In order to avoid eccentric stresses in the chord, the center lines of the diagonal rods, or the gauge lines of the angles, if these are used, should intersect on the center line of the chord. Such an arrangement, however, is not practicable if rods are used, nor advisable if angles are employed, as in the former case it is practically impossible and in the latter the gusset plates would become large and too expensive. For this reason it is a more common method to have the center lines meet on the gauge line of the outside channel in case of rods, or ~~in~~ the inside channel in case of angles. In the older types of bridges the rods were attached directly to the pin, the loop being bent to the proper angle

and slipped over the pin outside of the chord, being held in place by the pin nut (see Fig's 38 and 41, Pl. 5). This method is no longer used, as the bent eyes were found to be wanting in strength and rigidity, and besides this connection increases the bending moment on the pin.

The rods are usually connected with the upper chord by means of standard connections or lateral hitches as shown shown by Fig's 27, 29, 30, 33, Pl. 4, and Fig's 37(a), (b), 38, 41, Pl. 5, and Fig. 56, Pl. 6.

Fig. 27, Pl. 4, shows a top lateral connection consisting of two angles placed back to back and riveted to the batten plate. The lateral rods pass the hole in the out-standing legs of the angles, the rods and the legs of the angles being at right angles to each other. This form of construction is bad, for it develops tensile stresses in the two rivets of the outside angle, due to the bending moment of the stresses in the lateral. Notice, further, that the center lines of the rods intersect beyond the gauge line of the outside channel.

On the right-hand side of Fig. 29, Pl. 4, is shown a top lateral hitch composed of two angles placed with their legs parallel to the rod, this being secured in position by a cotter pin. This is a simple, cheap and effective connection.

Fig. 30 shows a hitch made up of a Γ bent so as to bring the two flanges into the same plane. This is a strong connection, though somewhat more expensive than that in Fig. 29, on account of requiring a little more shop work.

Fig. 33, Pl. 4, shows a form of construction that ought to be universally condemned. Notice that the angles are riveted to the web of the inside channel, and consequently, the rivets are in direct tension.

Figs 37(a) and (b), Pl. 5, show lateral hitches composed of three angles each, instead of two as noted above. Notice that in Fig. 37(a) the third angle is put underneath the other two. There is some advantage in placing the third angle thus rather than as shown in Fig. 37(b), for it requires two rivets less. The use of three angles is uneconomical and unjustified, as the simple form of Fig. 29, Pl. 4, is entirely satisfactory.

Fig. 56, Pl. 6, shows a top lateral hitch composed of a single angle bent in a semi-circle and riveted to the cover plate. This connection distributes the stress over a larger area of the cover plate than any above mentioned, and is at the same time probably cheap, as it is always used by the Massillon Bridge Co, a well known builder of many excellent bridges.

Art. VIII. BOTTOM LATERAL SYSTEM.

Like the upper laterals, the bottom laterals are made either of tension rods adjustable by means of screw and nut, or of angles. Less common practice is to employ adjustable loop rods with turn-buckles or sleeve nuts. In all cases the rods are attached to the floor beams, which also act as struts. This design is not good in connection with a suspended floor

beam, since the latter being several inches below the pin permits considerable vibration. In former times, when built-up floor beams were used, there was an objection to employing the web of the beam as a strut; but this objection is no longer sustained since rolled I beams are now employed, as the web of the latter is sufficiently strong to resist compressive stresses due to the lateral rods. The more common standard lateral connections are shown in Fig's 26, 31, 32 (a), (b), 34, Pl. 4, and Fig's 52, 54, 55, Pl. 6.

Fig. 26, Pl. 4, shows a method of connecting the bottom lateral rod to the pedestal. Notice that the rod is connected by means of a tap bolt passed through a plate riveted to the sole plate, and screwed into the latter. This construction is often used, as it is simple and effective, provided the riveting is strong enough to resist the moment of the lateral rod.

A somewhat different form of connection is shown in Fig. 34, Pl. 4. Notice that the lateral rod is forked and pin-connected to a bent plate which is riveted to the vertical plate of the pedestal. This form of construction is much inferior to that in Fig. 26, in that there is a bending moment in the plate and the pivots are subjected to tension.

Fig. 31, Pl. 4, shows a bottom lateral connection in which a gusset plate is riveted in the shop to the flange of the floor beam. The lateral rod is forked and secured to the plate by a pin as shown. Notice that by this construction the stresses pass through the flange of the I beam instead of through the web. This connection is

easy to make in the field and is probably more efficient than some methods to be described later.

Fig. 32(a) shows a top view, and Fig. 32(b), Pl. 4, an elevation of a bottom lateral hitch used by the Lafayette Bridge Co. This hitch is composed of two angles placed parallel to each other and riveted to one side of the web of the floor beam. One rod passes through a slot in the web and is secured to the two angles as shown in Fig. 32(a); while the other rod is pin-connected between the angles. This is a simple and cheap form of construction, and it is efficient if there is a sufficient number of rivets to make up for the tension resulting from the bending moment of the latter rod.

Fig. 52, Pl. 6 shows a construction similar to the Fig. 32, Pl. 4, except that the outstanding legs of the angles are cut to an arc of a circle, which is an improvement upon the form shown in Fig. 32, inasmuch as the same angles may be used regardless of the slope of the lateral rod. The malleable washer shown gives a firm bearing to the rod.

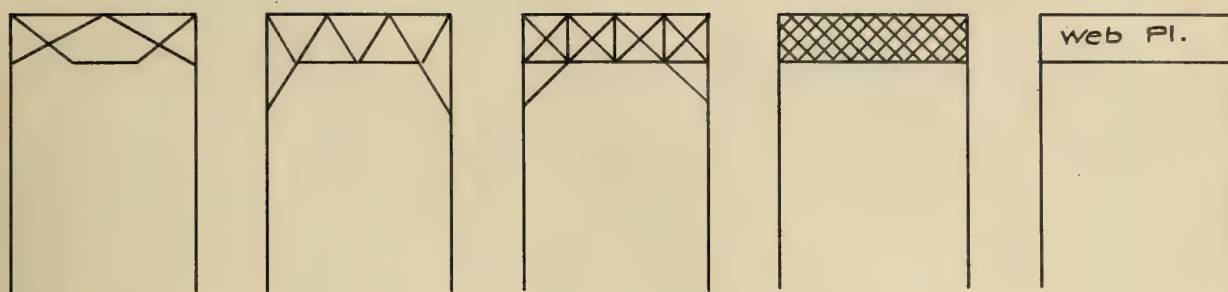
Fig. 54, Pl. 6, shows a lateral hitch composed of a gusset plate on each side of the web which is slotted to allow the passage of the laterals. The peculiar feature of this connection is that the rods belonging to the adjacent panels both pass through the slot in the web of the floor beam, and are fastened by a nut on opposite sides of the latter. Notice that if a spherical washer like the one shown in Fig. 52 is used, the rods may be adjusted in any required position.

Fig. 55, Pl. 6, shows a hitch similar to Fig. 54, except

that a cast-iron block is used instead of a bent plate. This block is reinforced by ribs as shown, and forms a very strong, though perhaps somewhat costly connection. As shown in the figure, the bearing of the rod on the rounded surface of the block is insufficient, and this detail would be improved by introducing a spherical washer between the nut and the block, similar to that shown in Fig. 52, Pl. 6. An objection to using cast iron in lateral hitches is that the cast iron being brittle soon fails under repeated stresses.

Art. IX. PORTALS & SWAY BRACING.

The stiffness of a bridge depends largely upon efficient forms of sway and portal bracing. The latter especially, should be as rigid as possible, since it takes the combined wind stresses due to the direct wind as well as those due to the overturning moment. Many bridge failures have been recorded which are due to the lack of lateral stiffness resulting from weak portals; and therefore it is necessary to design the main members as well as the connections to the main posts with special care. It is customary to design the web members of the portal bracing to take only tension, but for additional safety it is often specified to use shapes capable also of transmitting compression. The latter requirement is met by using angles for diagonals and either angles or channels for struts. There are many forms of portal bracing in use, the most common being shown diagrammatically below.



The portals may be connected to the end posts either through the cover plate or through the web of the channel. The latter method is somewhat better, as far as the proper distribution of stresses is concerned, although the former is frequently used. On both methods, as a rule, the upper strut of the portal bracing is connected to the top chord through a bent plate which is riveted to the cover plate, thus making the bracing more efficient than if the connection were made only to the end post.

Figs 35, 42 and 45, Pl. 5, show forms of portal bracing used in the bridges here investigated; while Figs 28 and 29, Pl. 4, show forms of connections commonly used for the portal shown by Fig. 42.

The requirements for sway bracing are not so severe as those for the portal bracing, as the wind stresses transferred are due to one panel length only. The top and bottom struts are frequently composed of two angles placed back to back separated by gusset plates, as shown in Figs 36, 39, 40, Pl. 5. Sometimes light lattice girders are used, or channels employed to good advantage, see Fig. 46, Pl. 5. The methods of connecting the sway bracing to the chord are shown in Figs 36, 39, 40, 41 and 46, Pl. 5. The riveted connection is no doubt more rigid, and is

preferable to the pin connection, although the latter is evidently cheaper.

The form of construction shown in Fig. 41, Pl. 5, deserves special attention as being too complicated and very difficult to erect.

Art. X. MINOR DETAILS.

Among the minor details deserving special mention properly belong: fence and hub-guards, pedestals or shoes, roller nests and cast bases.

Fence. The fence may be a simple gas-pipe railing, or a combination of angles and lattice bars, or one or more channels. The gas pipe fence is probably the most economical and consists of two gas pipes laid parallel and secured to the truss by simple loops. On bridges having special side walks outside of the trusses the gas-pipe fence is very satisfactory, and when properly constructed presents a neat appearance. A good form of construction consists of posts made of large pipes bolted firmly to a floor-beam bracket and properly braced. These posts carry horizontal pipes of smaller diameter, to which they are connected by standard four-way branch and T connections.

A simple form of hub-guard consists of two  bolted to the truss at the intermediate and end posts. Fig. 17, Pl. 3, shows the method of supporting the channels at the hip verticals. Many times the attempt is made to support the hub-guard simply by a clevis around

the hip verticals, but such ^{an} arrangement is at best only a makeshift. It is important that the channels be rounded off at the end posts in order to prevent a possible injury to horses coming too close to the hub-guard. A form of casting like that shown in Fig. 53, Pl. 6, is sometimes used to accomplish the same purpose.

Fig. 51, Pl. 6, shows a form of fence composed of angles and lattice bars.

Pedestals. Fig. 26, Pl. 4, shows a pedestal composed of a single base plate. Notice that the end post rests directly on the plate and is secured to it by two angles.

Fig. 34, Pl. 4, shows a sole plate of a pedestal. On this case the end post is riveted to the sole plate supported by rollers. Notice the narrow strip at the middle riveted to the bottom of the plate, the use of which is described in the next paragraph.

Roller Nest. Fig. 50, Pl. 6, shows the most common form of roller nest composed of four rollers held together by a frame of iron bars which are so arranged that the rollers move freely between them. Notice the groove at the center of each roller, which is designed to prevent the rollers from moving laterally, the groove running on two strips of metal riveted to the roller- and the base plate respectively.

Cast Base. Fig. 49, Pl. 6, shows a simple form of cast-iron base which is sometimes used to raise the fixed end of the bridge to the same level as the roller end, in order that both masonry abutments may be built to the same level.

Art. VI. ESTIMATE OF COST.

On Tab. I following is an estimate of the cost of the highway bridge investigated by the author in the regular class work of his senior year. The estimate is based upon the following data which were furnished by the Instructor:

Cost of metal f.o. b. cars at Pittsburg.

CS & IS	\$ 1.60 per lb.
Plates	1.60 " "
LS	1.60 " "
Loop Bars	1.80 " "
Eye bars	1.80 " "
Lacing "	1.80 " "
Pivots	2.10 " "
Pin Rounds	1.80 " "
Turn Buckles	7.50 " "
Bolts per 100	\$ 13.00
Washers per 100	\$ 1.00
Spikes (50d)	\$ 2.50 per 100 lbs.

3% was added to the amount of metal to cover the waste. The average shop cost was taken at 0.75¢ per lb., and the cost of making drawings was assumed at \$2.00 per ton, which the writer has since been informed is too low. The cost of white oak lumber was taken at \$25.00 per 1000 ft. B. M. Hauling was estimated at 25¢ per ton-mile; erection \$1.00 per lin. ft.; paint \$1.00 per ton of metal; painting \$1.00 per ton of metal.* Bidding expenses were estimated at \$25.00, and traveling expenses to erect at \$30.00. Profit assumed at 10% of the total.

*See footnote on p. 29.



TABLE I.

Estimate of the Cost of a 110'-3" Pin-Connected Highway Bridge, Located at Monticello, Ill.

MATERIAL	Weight lbs.	% Total Wt of Metal	Unit Cost ¢ per lb.	Average Cost ¢ per lb.	Total Cost of Metal
Es and Is	27165	55.00	1.60	0.8800	\$
Plates	4512	9.10	1.60	0.1455	
Ls	2382	4.83	1.60	0.0773	
Lacing Bars	2677	5.43	1.80	0.0869	
Loop Bars and Rods	9762	19.70	1.80	0.3550	
Nuts	622	1.26	3.00	0.0378	
Rivets	1528	3.10	2.10	0.0651	
Pin Rounds	780	1.58	1.80	0.0284	
Turn-Buckles	—	—	7.50	—	
Total	49428	100.00		1.6760	830.00
Add 3% for Waste				=	25.00
Total Cost of Steel = \$					855.00
SUMMARY OF COST.					
Item	Cost	Item	Cost		
Steel	\$855.00	Painting *	\$ 25.00		
Shop Work	371.00	Paint **	25.00		
Drawings	50.00	Bidding Expenses	25.00		
Freight	82.00	Travel. Exp. to Erect	30.00		
Lumber	158.00	Total	1775.00		
Bolts	12.00	Profit (10%)	177.00		
Spikes	2.00	Grand Total	1952.00		
Hauling	30.00	Cost of Bridge per lin. ft.	\$17.70		
Erection	110.00	" " " " lb. of Metal	¢ 3.95		

* Superfluous, included in the cost of erection. [nearly correct.

** Too high, 1 gall. for each 10 ft., or 11 gall's at \$8.80 would have been more

TABLE II.

Table II below shows the Dimensions and Estimated Cost of the Superstructure of a Number of Pin-Connected Highway Bridges Investigated by the Civil Engineering Senior Class in the First Semester of 1904 - 1905.

Length of Span	Depth of Truss	Width of Roadway	Weight of Metal		Lumber Ft. B.M.	COST		
			Main Mem.	Details		Total	per lin.ft.	per lb. Metal.
70'-0"	17'-0"	14'-0"	19803	3456	3217	\$ 776.00	\$ 11.10	¢ 3.34
74'-0"	16'-0"	17'-0"	23292	5869	3740	1270.30	17.10	6.80
78'-9"	16'-1½"	16'-0"	21833	4031	3590	1631.30	20.90	6.31
80'-0"	18'-0"	14'-0"	19840	4833	3590	1067.88	13.35	4.30
"	16'-0"	14'-0"	24272	5748	3710	1195.00	15.00	4.00
"	"	15'-0"	25306	3942	3691	1386.25	17.32	4.06
"	"	17'-0"	25142	3457	3600	1092.63	13.66	3.30
"	18'-0"	14'-0"	19955	2287	3500	922.20	11.52	4.50
"	16'-0"	15'-0"	24275	4918	3620	1058.25	14.55	3.90
"	"	"	23775	4665	3610	1456.80	18.21	4.80
"	"	"	24150	5001	3630	1507.70	18.85	4.90
"	"	"	24552	5535	3610	1176.20	14.70	5.20
"	"	14'-0"	12238	4109	3640	1178.70	14.10	4.40
"	18'-0"	"	29776	—	3600	1250.94	15.67	4.20
"	17'-6"	"	24798	4984	3661	1208.80	15.11	4.59
"	10'-0"	15'-0"	20975	2538	3199	772.64	10.73	2.60
90'-0"	18'-0"	14'-0"	58149	—	5180	1526.76	17.00	6.00
"	20'-0"	15'-0"	27009	5552	4170	1342.25	15.00	4.10
"	18'-0"	14'-0"	27000	5583	3990	1256.00	13.96	3.90
92'-0"	"	15'-0"	27328	6437	4315	1375.10	14.95	4.07
"	"	14'-0"	32625	—	4185	1758.80	19.12	5.40

Table II. Con'd.

Length of Span	Depth of Truss	Width of Roof	Weight of Metal		Lumber Ft. B.M.	COST		
			Main Mem.	Details		Total	per lin.ft.	per lb. Metal
96'-0"	18'-0"	17'-0"	28962	3851	4780	\$1220.39	\$12.72	\$3.74
100'-0"	"	14'-0"	25193	3819	11050	1297.60	12.98	4.39
"	"	"	32923	6810	4610	1620.00	16.20	4.05
"	17'-0"	"	34862	6939	4570	1803.75	18.04	4.56
"	18'-0"	"	34192	7651	5500	1692.60	16.90	4.04
"	18'-6"	15'-0"	31241	10738	5140	2140.80	21.40	6.50
"	18'-0"	"	33758	6909	5010	1118.20	11.18	5.14
105'-0"	21'-0"	18'-0"	35753	5719	5410	1625.00	15.47	3.90
"	20'-0"	14'-0"	33330	7103	4465	1577.90	15.02	6.00
108'-0"	20'-0"	16'-0"	34951	6395	5515	1712.00	15.85	4.15
"	16'-0"	18'-0"	41309	—	5515	1634.49	15.13	3.95
110'-0"	19'-0"	14'-0"	27922	4815	4990	1335.50	12.14	4.10
110'-3"	20'-0"	19'-0"	41434	5452	6115	1865.67	16.95	3.90
110'-0"	18'-4"	16'-0"	38732	6461	5810	1806.00	16.42	4.00
120'-0"	21'-0"	"	46957	6001	17920	1869.34	15.58	5.40
"	"	17'-0"	39493	5266	6375	1780.73	14.84	3.83
"	20'-0"	16'-0"	37961	6538	6060	1858.70	15.50	4.08
124'-0"	21'-0"	"	47402	6807	5760	2180.93	17.58	4.40
"	"	17'-0"	53141	5820	7790	2638.00	21.30	4.48
"	20'-0"	16'-0"	41385	5596	15720	2085.00	16.80	4.54
140'-0"	21'-6"	15'-0"	48908	7708	6245	1833.50	14.50	4.00
160'-0"	24'-0"	16'-0"	69548	12013	8998	3073.50	19.17	3.78
180'-0"	27'-0"	15'-0"	109265	—	8000	3946.36	22.48	3.61
190'-0"	33'-0"	14'-0"	81398	13448	8610	4199.50	22.10	3.22
273'-0"	38'-0"	18'-0"	151732	21391	17480	6375.00	23.35	3.68

TABLE I.
General Information Concerning Bridges Investigated.

	Length of Span	No of Panels	Distance c.c. of Trusses	Depth of Truss c.c. Chords	Camber	Angle bet. Vert. & Batter Brace	Name of Builders-
1	144 11 $\frac{1}{2}$	9	17'-0"	22'-0"	$\frac{1}{4}$ " in 10 ft.	36° 10'	Massillon Bridge Co.
2	126 5	7	15'-0"	21'-0"	$\frac{7}{32}$ " "	40° 40'	"
3	124 0	7	17'-0"	21'-0"	$\frac{7}{32}$ " "	40° 15'	"
4	151-1 $\frac{1}{2}$	9	18'-0"	22'-00"	$\frac{1}{4}$ " "	38° 40'	Grotom Br. & Mrig Co.
5	100-0	6	17'-0"	16'-8	$\frac{7}{32}$ "	45°-0	La Fayette Br. Co.
6	108'-0"	6	15'-0"	18'-0"	$\frac{7}{32}$ " "	45°-0'	"
7	125'-0"	8	17'-0"	20'-0"	$\frac{5}{16}$ " "	38°-0'	"
8	78'-"	5	29'-4"	10'-0"	$\frac{1}{4}$ " "	57° 20'	"
9	65'-4"	4	14'-0"	8'-0"	$\frac{5}{16}$ " "	63° 30'	"
10	63'-0"	4	20'-0"	7'-10 $\frac{1}{2}$ "	$\frac{1}{4}$ " "	63° 20'	"
11	70'-0"	5	15'-0"	17'-0 $\frac{1}{32}$ "	$\frac{5}{32}$ " "	39° 30'	"
12	176'-0	8	16'-0"	32'-0"	$\frac{5}{32}$ " "	34° 30'	The Toledo Br. Co.
13	134'-0"	8	17'-4"	22'-0 $\frac{1}{32}$ "	$\frac{3}{64}$ " "	36° 40'	Variety Iron W. Co.
14	160'-0"	8	17'-0"	24'-0"	$\frac{1}{4}$ " "	40°-0'	Indiana Br. Co.
15	110'-3"	7	19'-0"	20'-0"	$\frac{3}{32}$ " "	38° 15'	"
16	100'-0"	6	15'-1"	18'-0"	$\frac{7}{32}$ " "	42° 50'	Joliet Br. & Iron Co.
17	80'-0"	5	15'-1"	16'-0"	$\frac{5}{16}$ " "	45°-0'	New Castle Br. Co.
18	180'-0"	9	17'-4"	27'-0"	$\frac{1}{4}$ " "	36° 30'	Chicago Br. & I. Co.
19	110'-0"	6	19'-1"	20'-0"	$\frac{7}{32}$ " "	42° 30'	"
20	120'-0"	8	17'-0"	20'-0"	$\frac{11}{32}$ " "	36° 50'	Pan Am. Br. Co.
21	80'-0"	5	14'-10"	18'-0"	$\frac{5}{16}$ " "	41° 40'	King Br. & Iron Co.
22	100'-0"	5	17'-0"	20'-0"	$\frac{3}{16}$ " "	45°-0'	Canton Bridge Co.
23	80'-0"	5	15'-0"	16'-0"	$\frac{7}{32}$ " "	45°-0'	"
24	120'-0"	7	17'-0"	21'-3 $\frac{1}{2}$ "	$\frac{7}{32}$ " "	38° 56'	Wisconsin Br. Co.
25	100'-0"	6	17'-4"	16'-8"	$\frac{7}{32}$ " "	45°-0'	Wrought I. Br. Co.
26	80'-0"	5	15'-0"	18'-0"	$\frac{5}{32}$ " "	41° 40'	Attica Br. Co.



Fig. 1.

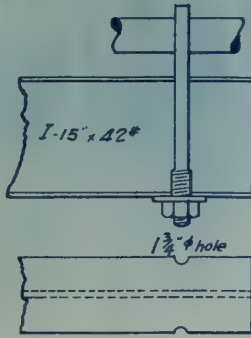


Fig. 2.

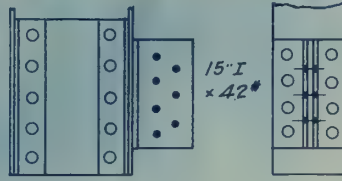


Fig. 4.



Fig. 3.

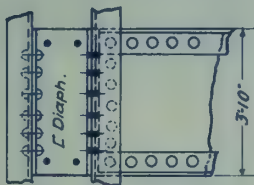
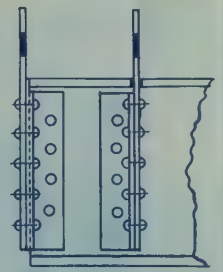


Fig. 5.

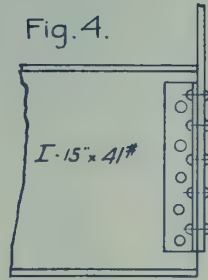
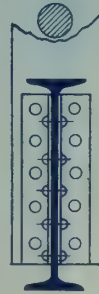


Fig. 7.

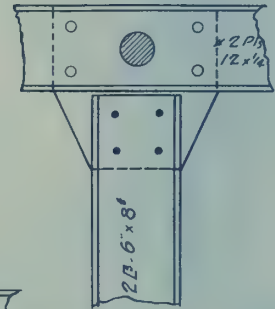


Fig. 6.

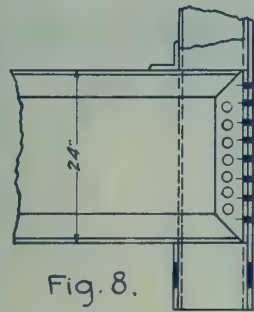
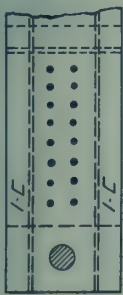


Fig. 8.

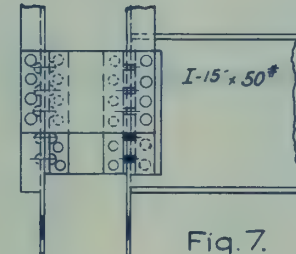


Fig. 9.

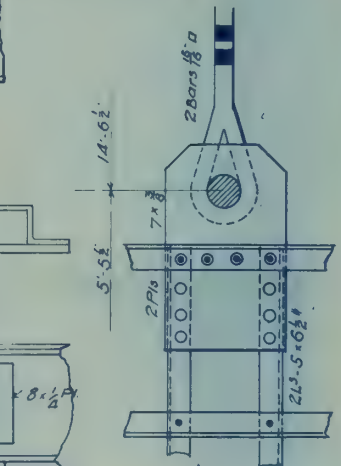


Fig. 13.

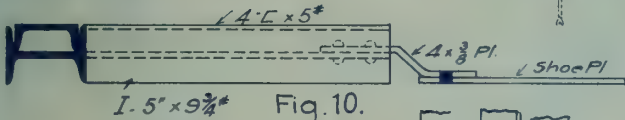


Fig. 10.

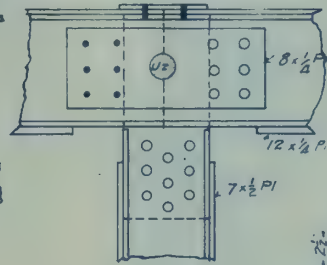
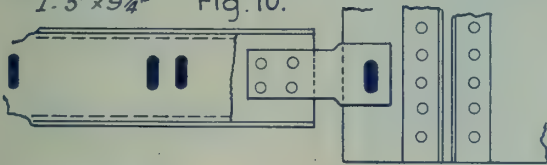


Fig. 12.

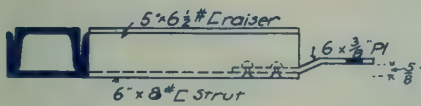


Fig. 14.

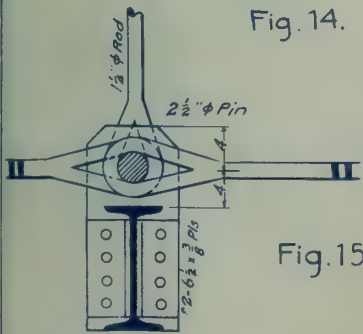


Fig. 15.

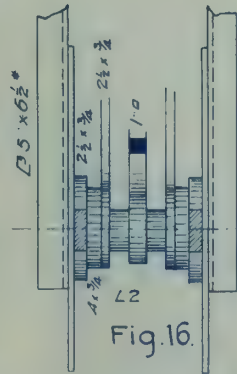
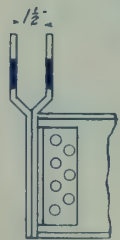


Fig. 16.

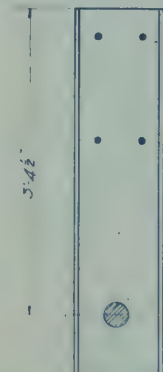


Fig. 17.

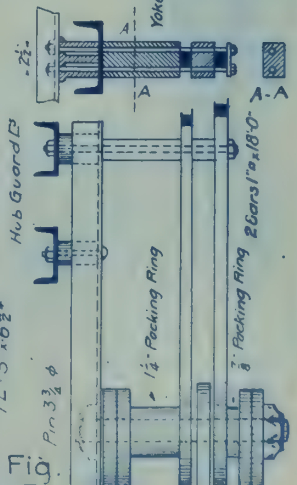




Fig. 18.

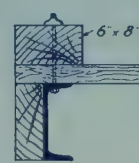
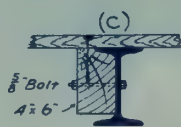


Fig. 19.

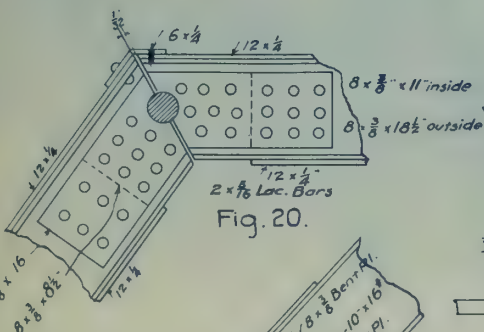
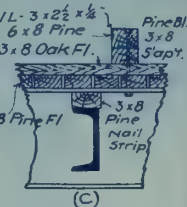


Fig. 20.

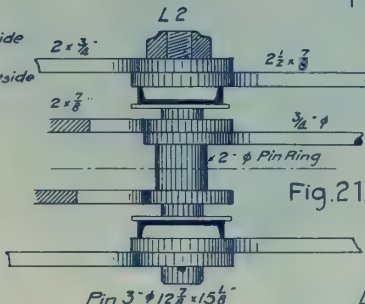


Fig. 21.

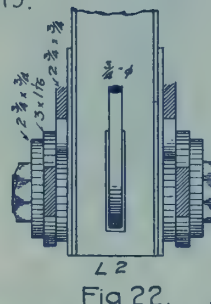


Fig. 22.

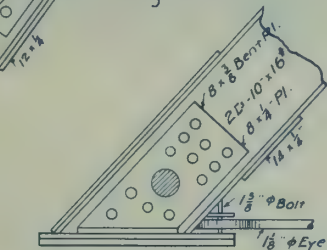


Fig. 26.

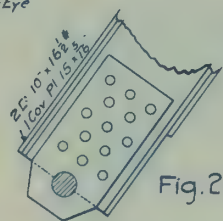


Fig. 25.

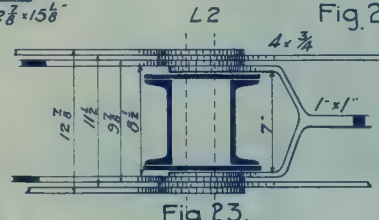


Fig. 23.

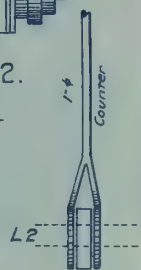


Fig. 24.

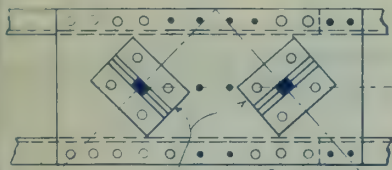
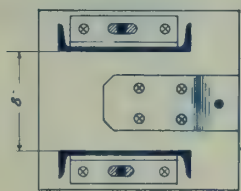


Fig. 27.

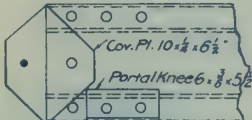


Fig. 28.

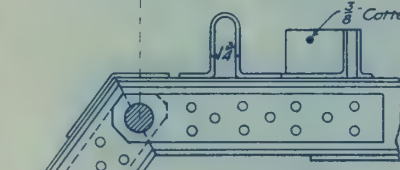


Fig. 29.



Fig. 30.

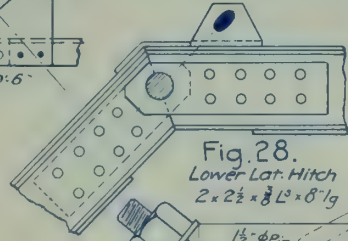


Fig. 31.

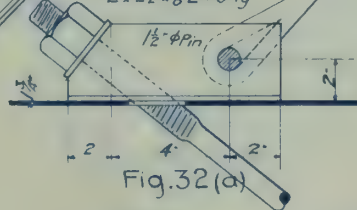


Fig. 32(a)

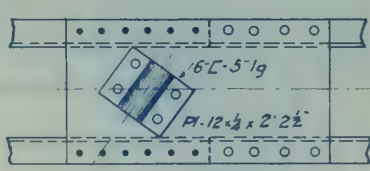


Fig. 33.

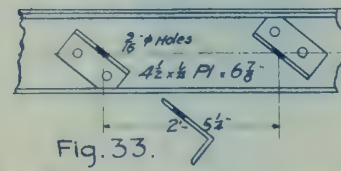


Fig. 34.

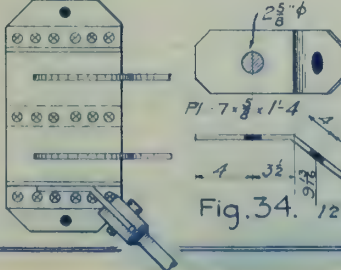


Fig. 32(b)

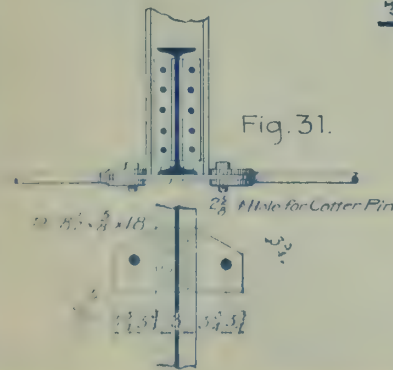


Fig. 31.

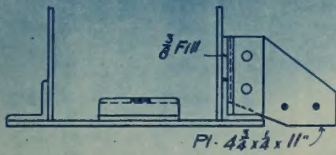


Fig. 48.

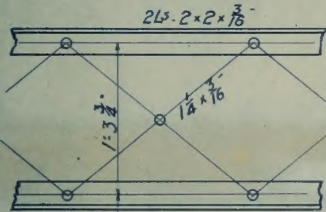


Fig. 51.

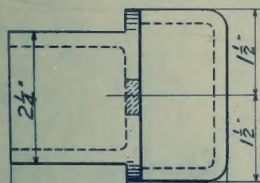


Fig. 53.

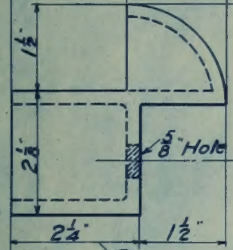
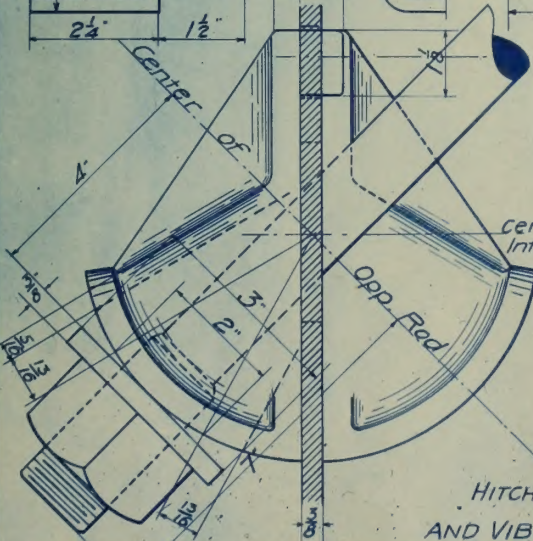
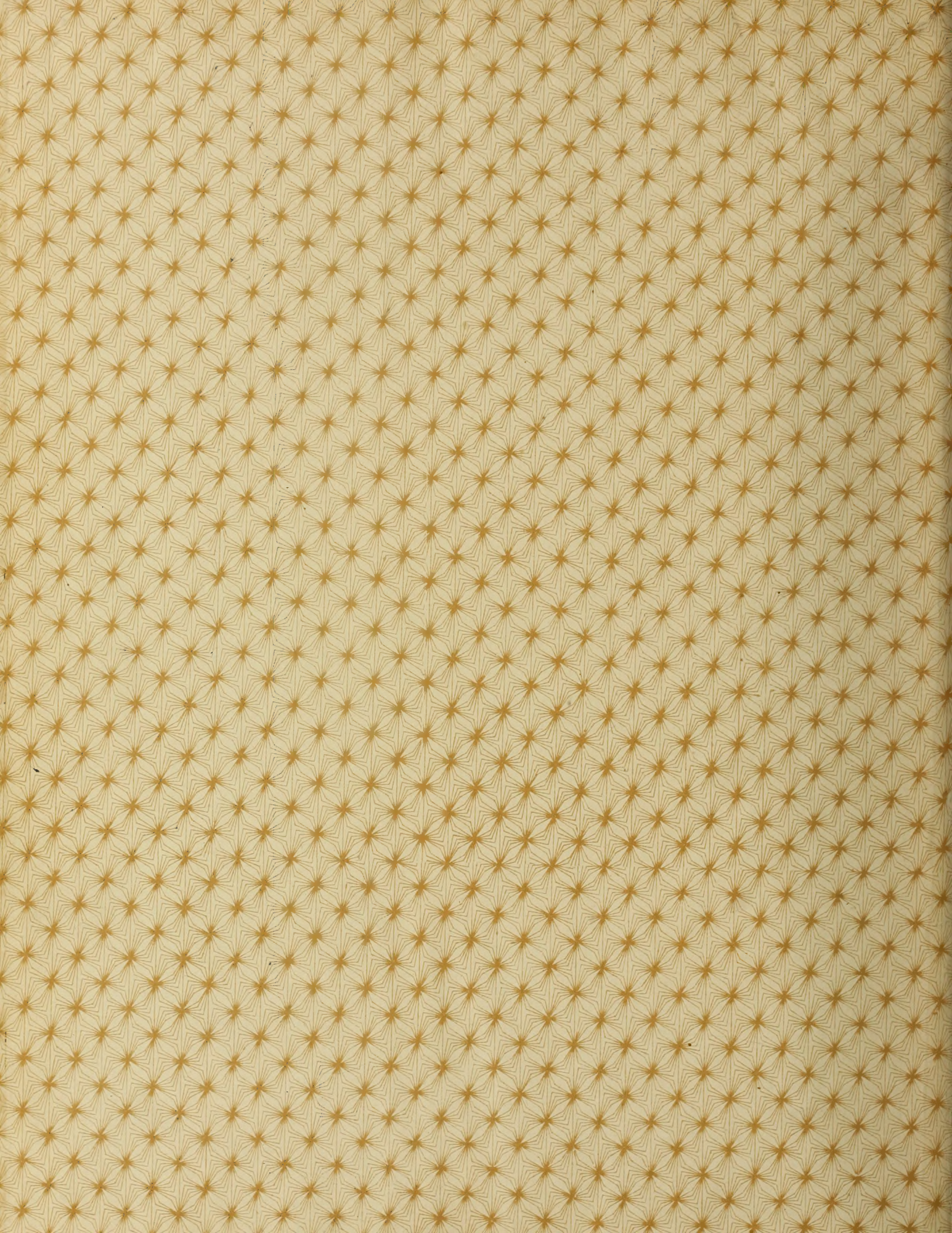


Fig. 54.







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